Optical Waveguide Amplifiers for Heterogeneous Integration in Optical Backplanes

Feridun Ay,[1] Jing Yang,[1] Tobias Lamprecht,[2] Kerstin Wörhoff,[1]
Bert Jan Offrein,[2] and Markus Pollnau[1]

[1] Integrated Optical MicroSystems Group, MESA+ Institute for Nanotechnology,
University of Twente, 7500 AE Enschede, The Netherlands
e-mail: f.ay@ewi.utwente.nl
[2] IBM Research GmbH, IBM Research - Zurich, 8803 Rüschlikon, Switzerland

1. Introduction

Interconnects between electronic cards via their printed circuit board (PCB) backplane have become a bottleneck in high-end systems as a result of the continuous increase of microprocessor clock rates and data transmission rates. Use of optical waveguides in optical backplanes and motherboards is a possible solution, because these are far less sensitive to electromagnetic interference than electrical interconnects and offer the potential of a much larger capacity. Polymers are promising as a waveguide material in this application due to their low cost and ease of fabrication. Recently, a 12-channel card-to-card optical interconnect link with embedded polymer waveguides and optical signal generation by a diode laser operating at 850 nm (due to the maturity of VCSEL technology at this wavelength) with data transmission up to 10 Gb/s per channel has been reported [1]. Investigations on the optical power budget for polymer-waveguide-based high-speed links via optical backplanes indicate that signal recovery by optical amplification to compensate the optical losses arising due to waveguide materials, signal routing, and input/output coupling is necessary [2].

In this work, the feasibility of signal amplification in optical backplanes via integration of Nd^{3+}-doped channel waveguide amplifiers is investigated. A maximum 0.21-dB internal net gain is demonstrated in a polymer - tapered $Al_2O_3:Nd^{3+}$ - polymer heterogeneously integrated structure.

2. Optical Backplane and Amplifier Waveguides

Nd^{3+}-doped polymer and Al_2O_3 single-mode waveguide amplifiers on Si substrates were investigated at the first optical communication window; similar optical gain of ~2 dB/cm was demonstrated [3, 4]. In $Al_2O_3:Nd^{3+}$ the waveguide geometry was then optimized to a multi-mode, large-core, 8-µm-wide by 3-µm-thick cross section for minimizing the coupling losses to the 6×6 µm^2 polymer optical backplane waveguides provided by IBM Research - Zurich (Fig. 1). By use of a waveguide structure horizontally tapered down to 2.5 µm (Fig. 2a) in order to increase the pump intensity and heterogeneously coupling this $Al_2O_3:Nd^{3+}$ tapered waveguide amplifier to either one or in between two polymer optical backplane waveguides (Fig. 2b), a maximum gain of 0.87 dB (Fig. 2c) and 0.21 dB, respectively, was demonstrated for light propagating through the complete structures [5]. The coupling losses were 1.33 dB and ~0.5 dB at the first and second interface. This result demonstrates that heterogeneous integration of optical waveguide amplifiers provides a potential solution for compensating losses in optical interconnects.

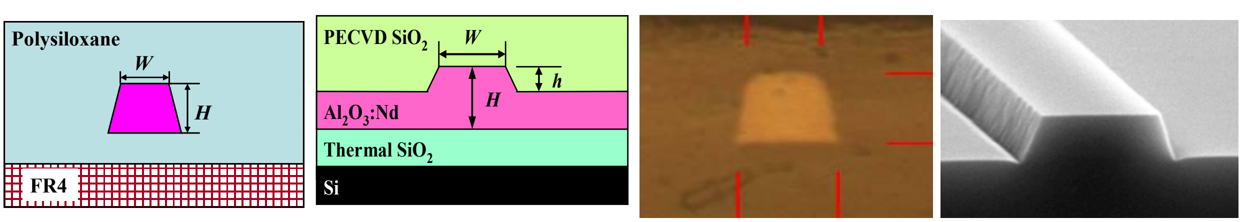

Fig. 1. Waveguide geometries (from left to right): schematic of the cross section of (a) polymer and (b) $Al_2O_3:Nd^{3+}$ waveguides; (c) optical microscope image of a polymer waveguide and (d) scanning electron microscope image of an Al_2O_3 channel waveguide without upper cladding.

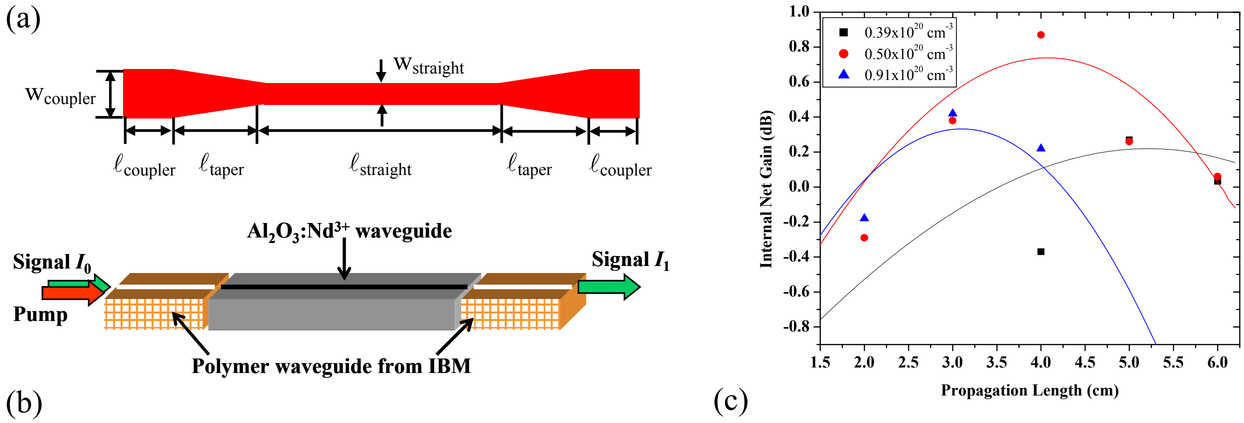

Fig. 2. (a) Top view of an Al_2O_3:Nd^{3+} tapered waveguide; (b) schematic of the demonstration of amplification in optical backplanes by coupling an Al_2O_3:Nd^{3+} waveguide to two polymer waveguides; (c) internal net gain of a polymer waveguide coupled with an Al_2O_3:Nd^{3+} waveguide versus propagation length in the Al_2O_3:Nd^{3+} waveguide for different Nd^{3+} concentrations.

Preliminary investigations of Al_2O_3 waveguide amplifiers for use in future single-mode optical backplanes operating at the second and third optical communication windows have been performed. A net internal optical gain of 5.1 dB [4] and 9.3 dB [6] at 1330 in Al_2O_3:Nd^{3+} and 1530 nm in Al_2O_3:Er^{3+}, respectively, was demonstrated for non-optimized waveguide structures in Al_2O_3. In the latter device, high-speed amplification of 170 Gbit/s has been reported [7], demonstrating that rare-earth-ion-doped amplifiers are well suited to provide signal recovery in optical data transmission.

3. Conclusions

Large-core, tapered Al_2O_3:Nd^{3+} channel waveguides have been fabricated and optical amplification at a wavelength of 880 nm has been characterized. Amplification in optical backplanes has been demonstrated by inserting such Al_2O_3:Nd^{3+} channel waveguides in between two polymer waveguides. A maximum 0.21-dB internal net gain has been demonstrated in an Al_2O_3:Nd^{3+} waveguide coupled in between two polymer channel waveguides. The gain can be improved by increasing the pump power and adjusting the waveguide geometry and dopant concentration for the chosen pump power. Use of such rare-earth-ion-doped waveguide amplifiers can provide a solution for compensating the losses occurring in optical interconnects.

4. Acknowledgments

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5. References

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